현수교의 경관설계 방법과 시점장

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Landscape Design Method and View Point Field of Suspension Bridges

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요 약

교량설계에 있어서는 교량의 기능과 안전성, 경제성 등 구조 공학적인 면을 고려하여 설계하게 되는데 최근에는 교량의 경관설계에 관해서도 많은 관심을 갖고 있다. 그러나, 국내에선 교량의 구조적인 측면에서의 연구는 활발하게 이루어지고 있으나 교량의 경관설계에 대한 연구는 거의 이루어지고 있지 않다. 따라서, 본 연구의 목적은 교량의 구조 공학적인 판단과 경관 공학적인 판단에 의해서 교량 형식을 결정하는 방법과 선호도가 높은 현수교의 시점장을 분석하는데 있다. 교량형식을 결정하는 방법은 기초설계단계에서 Seen 경관을 고려하여 교량의 유형을 결정하고, 교량의 구조적인 정 · 동역학적 검토와 Seen경관 · Sequence 경관 등을 고려하여 교종의 형식을 결정하게 되는 각 단계별 설계조건에 따른 교량설계 방법을 흐름도로 제시하였다. 또한, 현수교의 시점장의 범위를 정량적으로 나타내기 위해서 교량전체에 대한 시선입사각, 가까운 쪽의 주탑에 대한 시선입사각, 가까운 쪽 주탑의 외관 크기에 대한 연직시각, 교량전체가 시야에 들어올 수 있는 수평시각 등을 주시실험 자료와 Professional 현수교의 사진에 의한 구조형태의 비율 등을 측정하여 분석 고찰한 결과 교량전체에 대한 시선입사각 $\alpha = (15\pm7.5)°$, 가까운 쪽의 주탑에 대한 시선입사각 $\gamma = (30\pm7.5)°$, 가까운 쪽 주탑의 외관 크기에 대한 연직시각 $18° \leq \delta\ 27°$, 교량전체가 시야에 들어올 수 있는 수평시각 $\theta \leq 60°$의 시점장을 얻을 수 있었다.

주요어 : 구조공학, 경관공학, 근경관, 원경관, 현수교, 시점장

I. INTRODUCTION

In Korea, it is no exaggeration to state that prior to the 1980′s, the primary considerations of bridge construction were limited to structural safety and financial economy. However, given the unprecedented economic growth since 1980, precipitating in a phenomenal increase in the number of automobiles, the function and necessity of bridges can no longer be restricted to structural integrity and economic prudence. In the future, bridges should be built with added consideration for the environmental consequences of high traffic levels such as noise and air pollution. As well, an aesthetic focus on both the structure and its relationship to the surrounding environment should be considered.

Particularly on the western and southern coasts, which are characterized by a topographically irregular coastline, a preponderance of islands of varying size, and approximately three quarters of the land mass mountainous, the necessity of bridges for land to island, island to island connection, and for accessibility through mountain ranges is obvious. Furthermore, there is an urgent need to expand an urban elevated road system to service the major metropolitan centers with a well balanced and aesthetically pleasing vehicular infrastructure in harmony with the existing architecture.

Although Korea has in recent years invested heavily in long-span bridge construction, it lags behind other countries, who have utilized the sophisticated technology available, to facilitate the accelerating tourism market. It is advisable to encourage the construction of long-span bridges, as well as other types of construction, in order to pro-actively enhance the viability of this highly competitive growth industry.

Whether specifically for the burgeoning tourism industry or for traditional territorial development, it is desirable to consider environmental preservation and harmonious balancing between nature and structure as a priority. The "function first" paradigm of practically, safety, and economical conservatism should be expanded to include aesthetic sensibilities which will foster a value added dimension to the juxtaposed landscape by providing rest areas and services which compliment rather than alienate a variety of bridge structures constructed within the existing landscape.

The purpose of this study is to clarify the role played by both structural engineering and landscape engineering in bridge construction and to examine landscape design methods which integrate aesthetic value with structure and environment utilizing rest areas and parks located in such a way as to provide the best view of the bridge.

II. STRUCTURAL ENGINEERING AND LANDSCAPE ENGINEERING

Structural engineering concerns are fundamentally objective in nature. The singular focus is on primary functions such as structural integrity and cost effectiveness. Landscape engineering focuses on the formal aesthetic element, including shape, color, line, texture, and scale of the structure and its relationship to the environment. While artistic considerations are highly subjective, practicality designates form to follow function, therefore enforcing a degree of objectivity.

It is not essential to employ a structural engineer and a landscape engineer to make their respective determinations. A landscape engineer can competently satisfy all components. It is crucial however, that structural and aesthetic concerns are balanced so as to meet all criteria. To this end, it is necessary to clarify the process of bridge design from a landscape engineering perspective.

III. METHOD OF BRIDGE LANDSCAPE DESIGN

1. Basic Design and Seen Landscape

As depicted in figure 1., both structural and landscape engineering decisions are based on a central criteria list. All bridge construction is first and foremost based on the limitations imposed by the client. Community interests, industrial activity, political liabilities, and budgetary restrictions all contribute to the ultimate agreed upon action. The initial decision of location is determined after consideration of all mechanical or working conditions in conjunction with environmental impact and emphasis on harmonious balance. Then, geographical features such as the nature of the soil, alinement, crossroads, etc. must be investigated and determined to be acceptable at the chosen location. At this point, the type of bridge including length and span is selected (figure 6.). This decision takes into account the aesthetic elements of the proposed structure and its relationship to the Seen Landscape of the environment.(Represented by figures 1-5)

2. Bridge Type and Seen Landscape

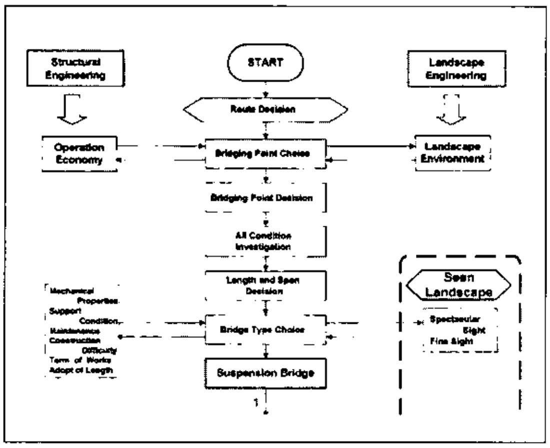

Figure 1. Basic Design and Seen Landscape

The bridge type is not selected exclusively by design as many factors will contribute to the ultimate decision including client preference, financial restrictions and public acceptability. The span length is a fundamental factor in the decision of a bridge type. This study focuses on the construction of a suspension bridge and investigates the adaptability of traditional and nontraditional designs. A nontraditional suspension bridge should only be considered after all traditional criteria have been met and it is found improvements may be possible. Regarding a long span, which is technically difficult, any alterations must be reviewed from both a structural and a landscape engineering perspective. In the case of short spans, consideration must be made for economic viability which may suggest an alternative bridge type. While aesthetic compromise may be reached, structural integrity must be maintained. Any suggested changes are subject to ongoing critical analysis and revision from a structural perspective. At this point in the process, several viewpoints should be selected from a landscape engineering perspective and the entire plan reviewed.

3. Static Check and Seen Sequence Landscape

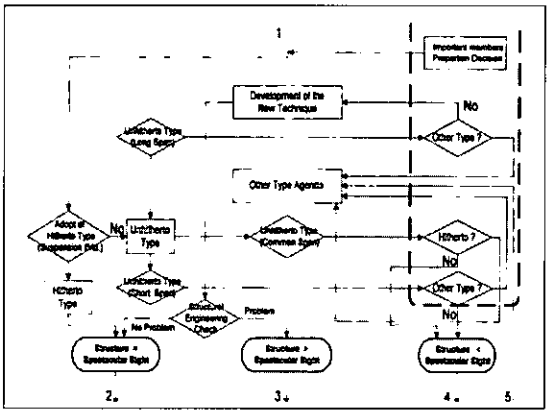

Figure 2. Bridge Type and Seen Landscape

At this stage, a rough design for the selected bridge type is drawn. From a landscape engineering viewpoint, structural components are created using the elements of form and including detailed subsidiary materials. Design decisions are reviewed by considering Seen Landscape (relationship between structure and environment) and Sequence Landscape (structure and relationship between components). A static check is performed. When actual stress exceeds permissible levels, the entire proposal must be re-evaluated through examination of design adjustment and possible alternatives of bridge type. Conversely, when the stress levels are negligible, the entire proposal should be reviewed in terms of unnecessary excessive cost which may suggests a more fiscally responsible design.

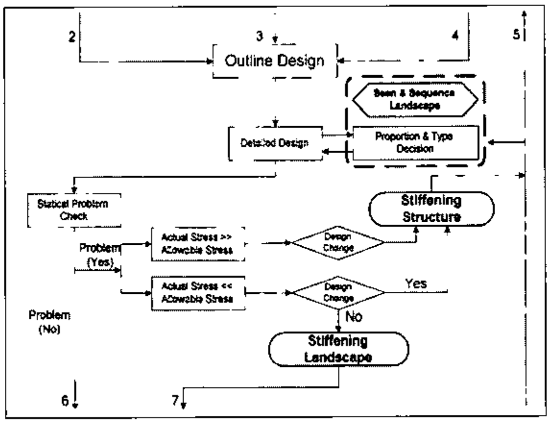

Figure 3. Static Check and Seen Sequence Landscape

4. Dynamic Check

Prior to conclusion of the bridge type decision process, a dynamic check should be conducted which includes tests for wind proofing, earthquake proofing, *et al.* When it has been verified that the designed structure exhibits structure stability and withstands tremors, after shock, galloping, rain vibration, etc., the chosen bridge type may be accepted. However, if any adjustments must be implemented in order to comply with dynamic standards a complete re-evaluation of the project is advisable.

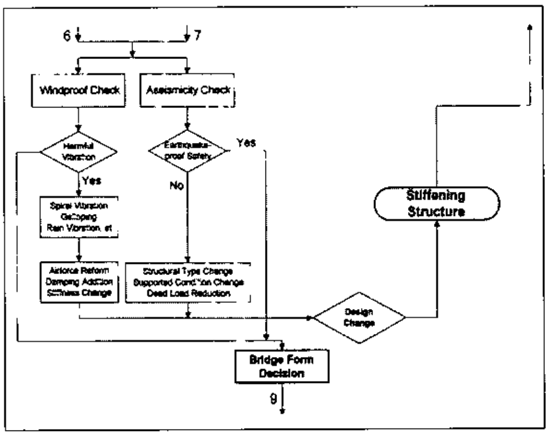

Figure 4. Dynamic Check

5. Engineering Check and Sequence Landscape

Once the bridge type has been determined, having met all existing static and dynamic criteria, a complete design which includes detailed plans of subsidiary materials including color and texture of lighting apparatus. While these decisions are primarily aesthetic in nature, and therefore in the

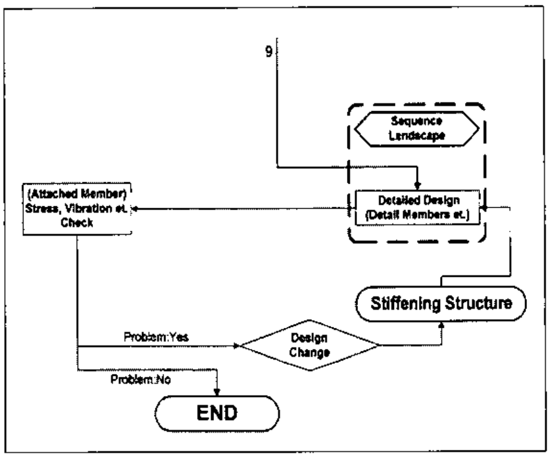

Figure 5. Engineering Check and Sequence Landscape

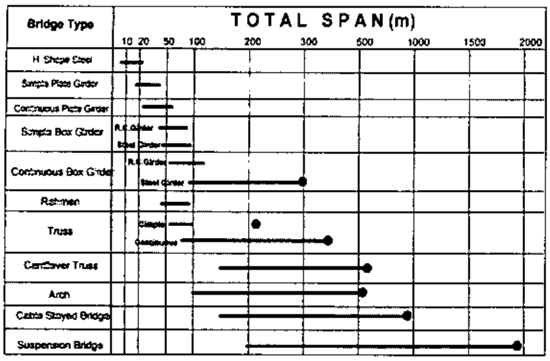

Figure 6. Span Length on the Bridge Types

realm of the landscape engineer, any additions or deletions must be evaluated in terms of impact on structural engineering.

IV. VIEWING AREAS FOR BRIDGES

Long span suspension bridges impact dramatically on the surrounding environment. Decisions on the placement of recreational areas which provide the optimum viewing advantage of the bridge must be included in discussion of the aesthetic merits of the overall project (Shinohara *et al.*, 1990). General guidelines adopted in landscape design include :

1. The scale of the structure greatly influences the landscaping decisions.
2. Viewing areas are limited by bridge location and topography.
3. With the exception of lighting, any extraneous development is inappropriate, as it only increases the costs.

Consequently, the extent of viewing area development is quite limited. This paper applies similar aesthetic methods to those followed for landscape development of cable stayed bridges (Shiomi *et al.*, 1994).

The relationship between the criteria essential to the viewing area location and the apparent sag ratio is clarified. As well, bridge proportions are calculated for a suspension bridge in conjunction with a corresponding viewing area. This study may provide practical application useful in the design of aesthetically appealing suspension bridges through consideration of viewing areas as an integral component of the overall design process.

1. Parameters for Viewpoint Selection

In order to propose the optimum vantage point, the following four widely accepted conditions are studied (Nakamura *et al.*, 1994) :

1) The angle of incidence α, which encompasses the complete structure.

2) The angle of incidence γ, which faces a main tower.

3) The vertical angle δ, which is dependent on the scale of a main tower.

4) The horizontal visual angle θ, which encompasses a view of the entire structure.

These notations are shown in Figure 7 (Shinohara 1996).

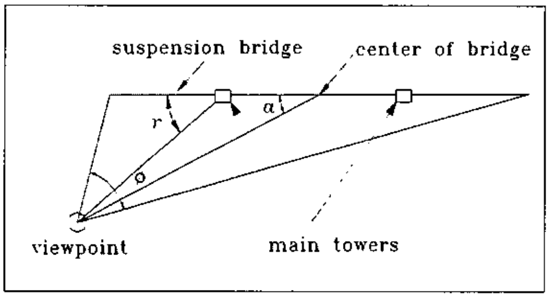

Figure 7. Relationship between suspension bridge and viewpoint (plane)

2. Angle of Incidence α

Twelve computer generated graphics (Figure 8) were considered in order to evaluate a variety of suspension bridge vantage points. A bridge design similar in design and proportion to the Innoshima

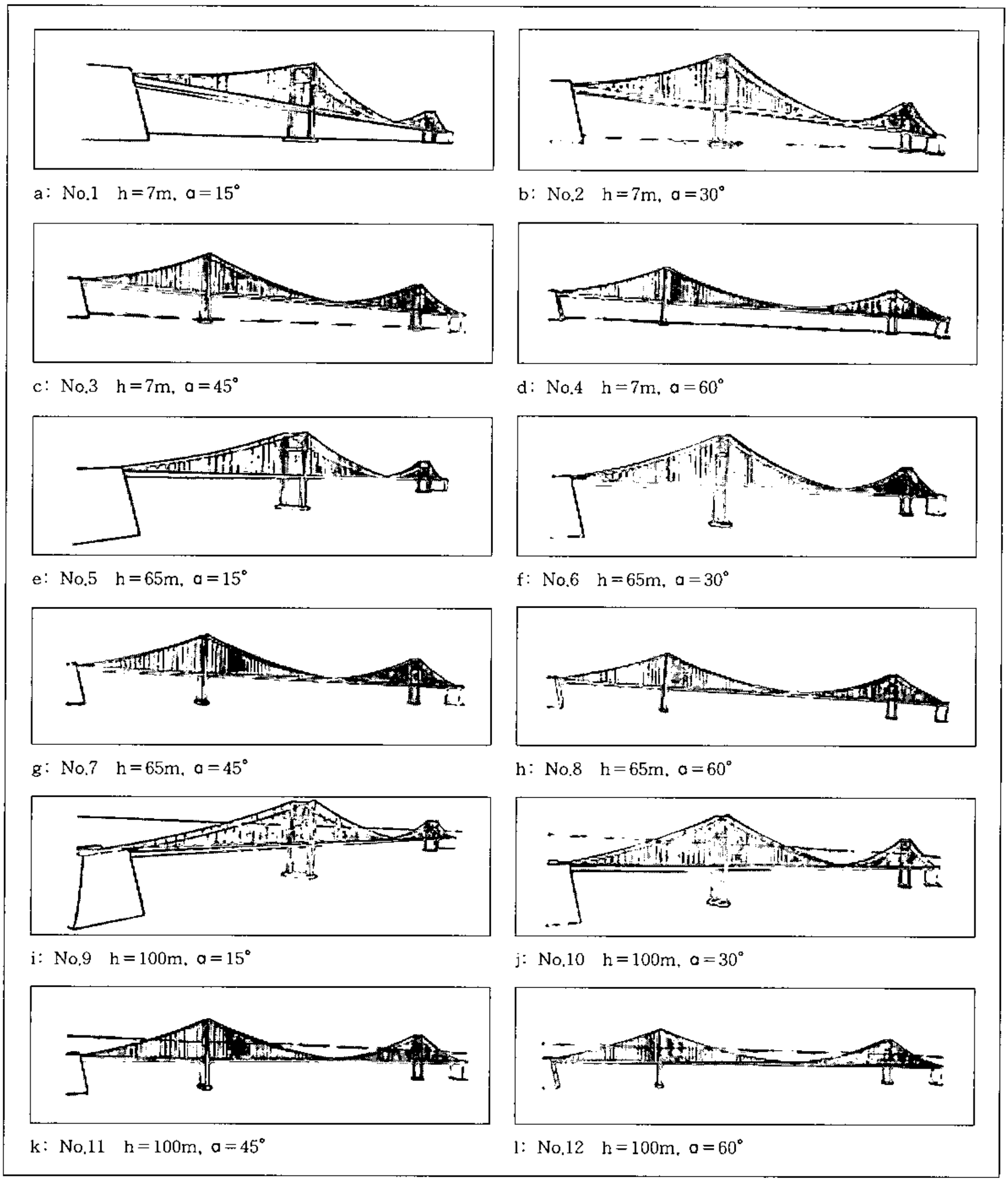

Figure 8. Computer graphics - twelve perspectives

Bridge was used.

Proportions generally accepted as well balanced are 0.3~0.5 for side by center span ratio (L_1/L), 0.25~0.38 for clearance ratio (h_1/H), 1/12~1/9 for sag ratio (f/L) (See Figure 9).

The appearance sag ratio ($\eta = f'/L'$) defined in

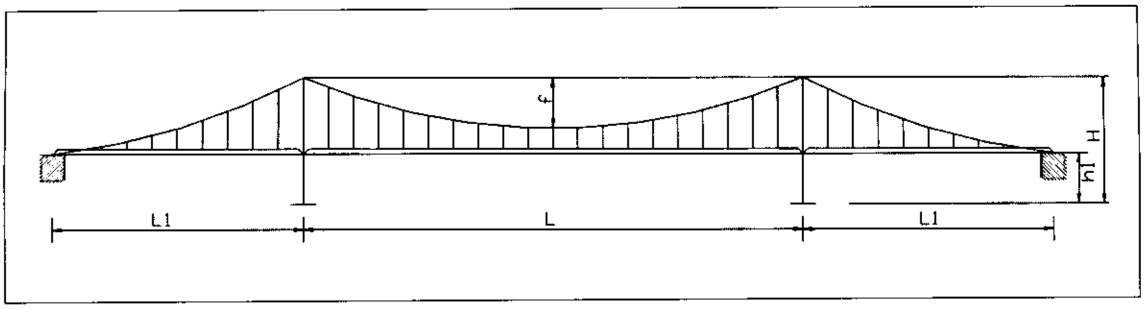

Figure 9. Notations for side view

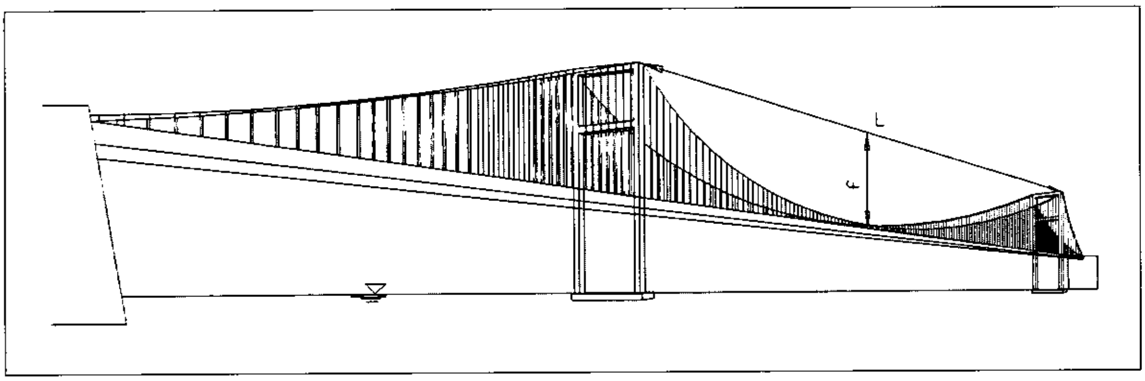

Figure 10. Notations for appearance sag ratio

Figure 10 was used to distinguish from the real sag ratio (η = f/L).

The model in this study has the side/center span ratio 0.33, the clearance ratio is 0.4 and the real sag ratio is 1/10. The heights of the viewpoints were selected as 7m (sea level), 65m (level of the girder), and 100m (distance between the top of the tower and the middle of the girder). The values of were 15 degree increments from 15 to 60 degrees. In a survey of 100 peoples (50 males, 50 females), a value of α = 15 degrees was determined as the preferred vantage point regardless of height, resulting in a proposed range for the angle of incidence of $\alpha = (15 \pm 7.5)°$

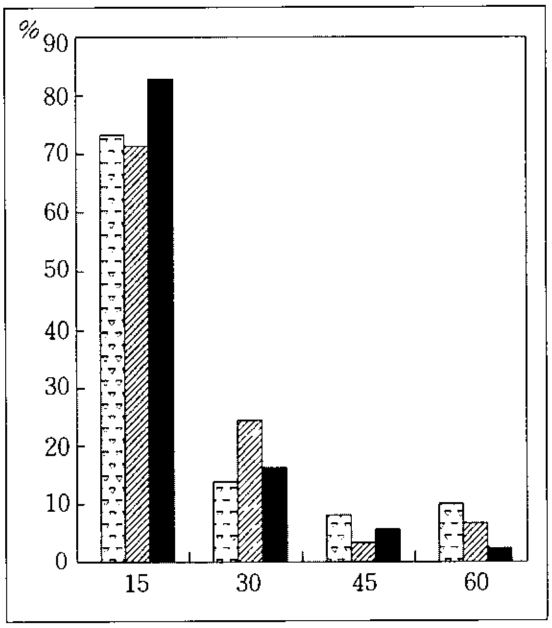

Figure 11. Distribution of favored α
Legend: ▢: h=7m; ▨: h:65m; ■: h=100m (n=100)

3. Angle of Incidence V

Three scale model prototypes were constructed

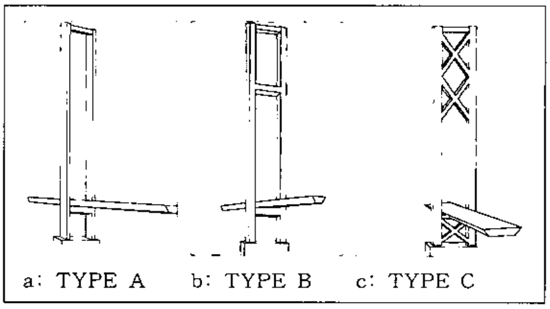

Figure 12. Models of main tower

(Figure 12). Each model was photographed from 4 camera positions (VP1 to VP4). Thus providing angle of incidence γ = 15, 30, 45, and 60 degrees. Sixteen photographs of each model were shown to the survey group. Photos were arranged in two groupings, one organized according to the height of the camera, the other according to the angle of incidence. Participants were to identify their preferences in each group. It was determined the overall favorite angle of incidence is approximately 30 degrees. The range of the angle of incidence γ is therefore parametrically proposed as $\gamma = (30 \pm 7.5)°$.

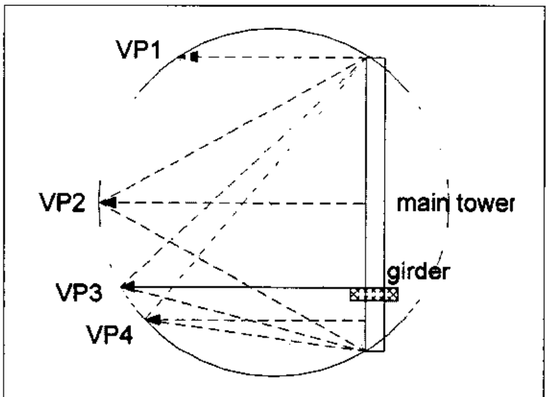

Figure 13. Camera position

Figure 13. Camera position

4. Vertical Angle δ and Horizontal Angle θ

The third condition for consideration is the vertical visual angle which is determined in relationship to the size while face a main tower. In Maerten′ s theory, a range of δ ($18° \leq \delta$ 27°) is considered acceptable for building facades. A similar range of can be applied for facing a main tower of a suspension bridge.

It is essential to consider the horizontal visual angle as well. Adopting Cone′ s theory ($\theta \leq 60°$) is sufficient. The horizontal visual angle is not as critical a parameter as the others since eye movement and neck rotation accompany visual inclusion. (Shiomi *et al.*, 1994).

By incorporating the four conditions, an effective viewing area can be established as shown in Figure 14

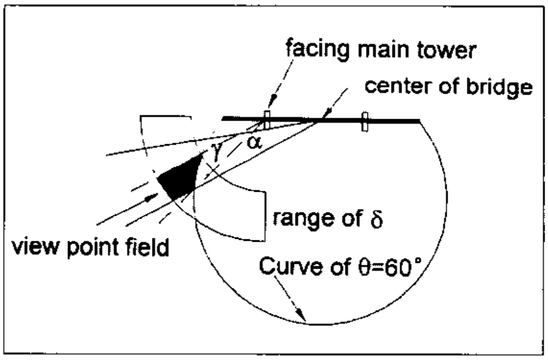

Figure 14. Proposed view point field

V. PROPORTIONS AND POINT OF VIEW

1. Apparent Sag Ratio

It can be determined through eye camera experiments that the apparent sag ratio η' is one of the important elements in the preferable composition. The numerical data of η' was collected from photographs in some publications on bridges. Figure 15 shows the result of data on η' which is based on a random sampling of 41 pictures. The most popular range of η' is $0.2 \leq \eta' \leq 0.3$. Concerning the relationship between the space and the figure of suspension bridges, the space intercepts convex arc created by the bridge that many in the survey group find aesthetically pleasing.

Almost the same results can be observed in case of apparent rise by span ratio r′ of the deck type arch bridges. For an arch bridge, survey 108 subjects were tested. Numerical data was collected in the same manner as with the apparent sag ratio of suspension bridges survey. The results are shown in Figure 16. In this figure, data includes 123 test results of the through type arch bridge are included. In the case of

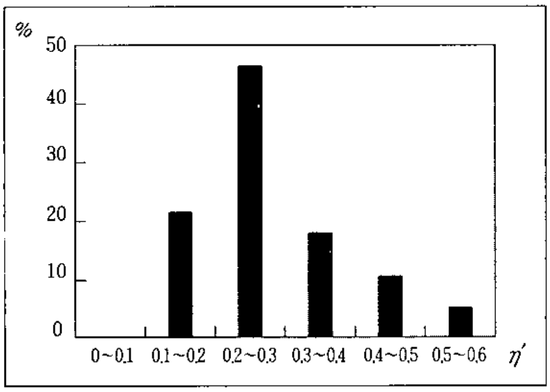

Figure 15. Distribution of η'
Legend: ■ : suspension bridges

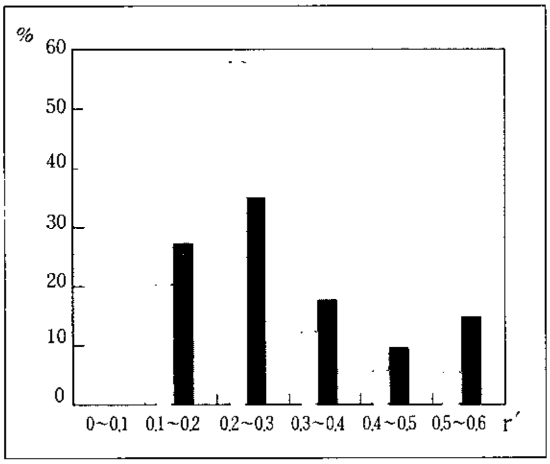

Figure 16. Distribution of r′
Legend: ▯ : desk type(n=108);
■ : through type(n=123)

the through type arch bridges, although the results are the same in range of $0.2 \leq r' \leq 0.3$ as the deck type one, this is a small quantity compared with the deck type. In the case of the arch bridge which intercepts the arc in space, survey subjects were noncommittal regarding visual opinion.

2. Relationship Between Apparent Sag Ratio η' and Angle of Incidence α

As shown in Figure 17, the shape of a curve of the main cable is assumed to be a parabola in Y-S plane. The cable along the center span is divided into 100 elements for numerical analysis. A point P in Y-S plane can be given by the equation.

$$Y_p = d - \frac{4f}{L^2} S_p(L - S_p)$$

Where SP = (L/2-S), and is the difference of height between the girder and the saddle on the tower. Let the axis Z be the direction of a line of sight and its orthogonal axis is X axis. After both of the coordinate transformation and perspective transformation, the point $P(X_T, Y_T, Z_T)$ in space coordinate given by the following equation will be obtained:

$$X_T = c \cdot \frac{S_p \sin\alpha}{S_p \cos\alpha + D'}, \qquad Y_T = c \frac{Y_p - ho}{S_p \cos\alpha + D'}$$

Where ho is the difference of height between the viewpoint field and position of girder, D' is the distance decided by the Corn theory, and c is the distance from the view point to the plane of projection. A coordinate Z_T is not included in this equation as it is not necessary in a two dimensional coordinate after the perspective projection.

The numerical analysis is required to obtain the relationship between the sag ratio η' and the angle of incidence α The mean value 0.25 and median 0.27 of η' from 17 existing bridges are used for the

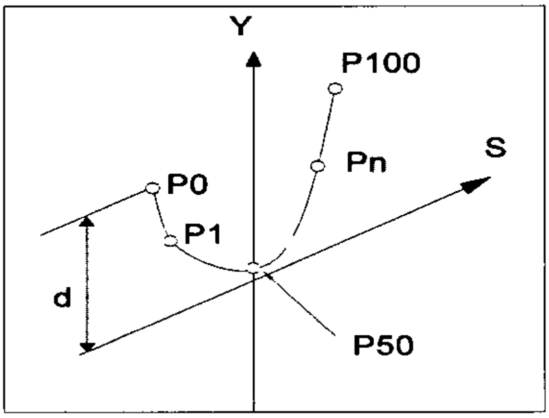

Figure 17. Coordinates of cable

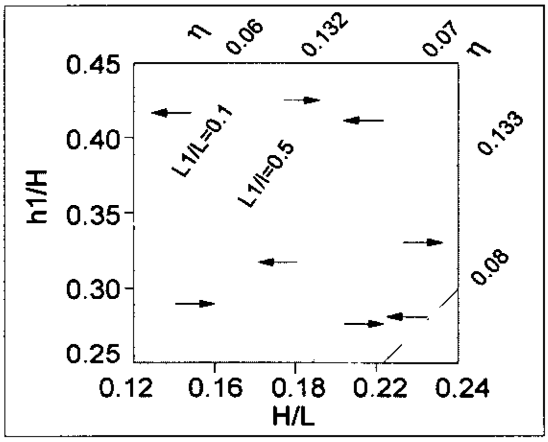

Figure 18. Balanced proportion(VP2)

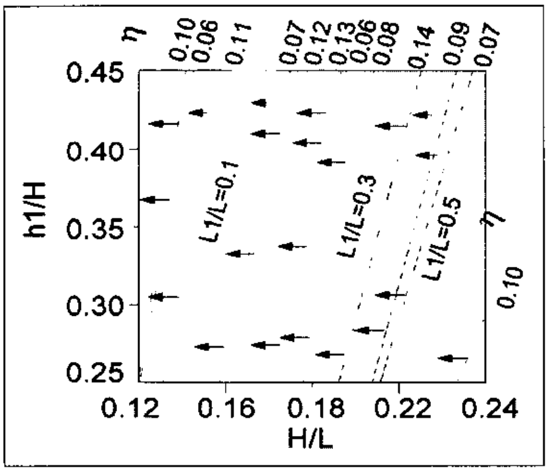

Figure 19. Balanced proportion(VP3)

numerical analysis. The relationship between the distance from viewpoint of individual height and α is obtained from the result of calculations. The angle of incidence exists in the proposed range (7.5° ≤ α ≤ 22.5°) under the condition in the range of η' (0.2 ≤ η' ≤ 0.3). Therefore, the apparent sag ratio is one of the important elements to determine the angle of incidence in preferable composition about suspension bridges.

3. Balanced Proportion of Suspension Bridge Which Satisfy Relation Between α and η'

A computer program for numerical analysis to obtain the ratios for principle proportion of suspension bridges which satisfy the relation between α and η' was made. In this program, ratios such that the span ratio (L_1/L), clearance ratio (h_1/H), the ratio of the height of tower to the length of center span (H/L), and sag ratio η' were used. Input data of these ratios are $0.1 \leq L_1/L \leq 0.5$, $0.25 \leq H_1/H \leq 0.45$, $0.12 \leq H/L \leq 0.24$ and $0.12 \leq \eta' \leq 0.14$, respectively, considering values of existent bridges.

The results of calculation for three different height of viewpoint field are shown in Figure 18, 19 and 20. The ratio h_1/H and H/L which satisfy the proposed relation between α and η' are indicated in the direction of the allows from the boundary lines for the ratio L_1/L and with η'.

All areas are not included in the figures 18 and 19. The details of the content for each height of the view point field are as follows.

VP2 : The conditions that all area satisfies the above relation are $0.06 \leq \eta' \leq 0.14$ with L_1/L=0.1 and $0.06 \leq \eta' \leq 0.14$ with L_1/L=0.5. The condition that all area does not satisfy is η' = 0.14 with 0.5.

VP3 : In the former case, the conditions are $0.09 \leq \eta' \leq 0.14$ with L_1/L=0.3 and $0.07 \leq \eta' \leq 0.13$

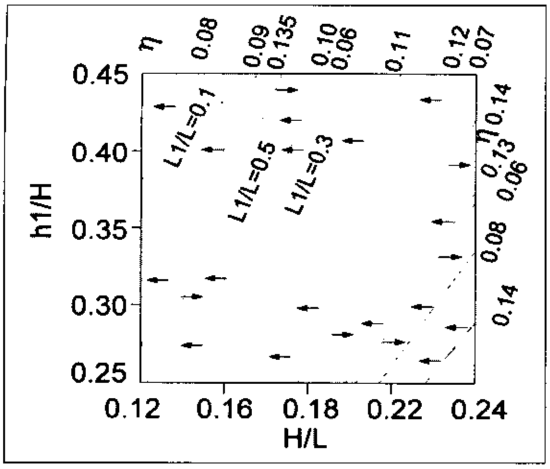

Figure 20. Balanced proportion(VP4)

with $L_1/L=0.5$. In the latter case, the condition is $0.06 \leq \eta' \leq 0.07$ with $L_1/L=0.5$.

VP4 : In the former case, the conditions are $0.11 \leq \eta' \leq 0.14$ with $L_1/L=0.5$ and $0.08 \leq \eta' \leq 0.13$ with $L_1/L=0.5$. In the latter case, the condition is $\eta' = 0.14$ with $L_1/L=0.5$.

Generally, the smaller the values of η' and L_1/L and the lower the view point field, the acceptable range proposed will be narrow.

VI. CONCLUSION

Conditions necessary for consideration include :

1. The angle of incidence about whole figure of the bridge is $\alpha = (15 \pm 7.5)°$.
2. The angle of incidence γ facing a main tower is $\gamma = (30 \pm 7.5)°$.
3. The vertical angle δ depending on the appearance size facing a main tower is $18° \leq \delta \leq 27°$.
4. The horizontal visual angle θ which includes whole figure of the bridge is $\theta \leq 60°$.

One of the important elements in suspension bridges is η', which is the so called apparent sag proportion seen from the viewpoint field. In order to determine the preferable appearance sag proportions, measurements were taken from published photos of a number of long suspension bridges. The relationship between the preferable apparent sag proportion η', and the incidence angle of the glance α are clarified by calculation.

As a result, we found a program for deciding the ideal which are real sag proportion, clearance proportion, proportion of side span, height of main tower/span, etc..

This study can be practical and useful in building a huge national memorial-park and designing suspension bridges having aesthetically beautiful proportions, based on the incorporation of viewpoint theory.

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